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14. ABSTRACT

Precision frequency metrology has valuable applications in cutting edge science, technology, and engineering. Current optical frequency standards utilize ultracold ions or atoms, which requires complicated, nonportable infrastructure. The novel technique in our proposal allows us to access the narrow linewidth properties of an optical clock transition in a thermal mercury vapor cell. Using a thermal vapor cell removes all of the complicated infrastructure requirements and leaves us with a portable system.

15. SUBJECT TERMS

optical frequency atomic clock

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Report Title

Two-Photon Optical Frequency Standard for Portable Optical Clocks Study

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Precision frequency metrology has valuable applications in cutting edge science, technology, and engineering. Current optical frequency standards utilize ultracold ions or atoms, which requires complicated, nonportable infrastructure. The novel technique in our proposal allows us to access the narrow linewidth properties of an optical clock transition in a thermal mercury vapor cell. Using a thermal vapor cell removes all of the complicated infrastructure requirements and leaves us with a portable system.

Enter List of papers submitted or published that acknowledge ARO support from the start of the project to the date of this printing. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

Received Paper

TOTAL:

Number of Papers published in peer-reviewed journals:

(b) Papers published in non-peer-reviewed journals (N/A for none)

Received Paper

TOTAL:

Number of Papers published in non peer-reviewed journals:

(c) Presentations

1. E.A. Alden, S. Degenkolb, T.E. Chupp, and A.E. Leanhardt, Prospects for Two-Photon Optical Magnetometry, DAMOP XLII, Altanta, GA, June 13 – 17, 2011.

2. K.R. Moore, E.A. Alden, and A.E. Leanhardt, Developing an Optical Atomic Clock with a Neutral Mercury Vapor, Midwest Cold Atom Workshop, University of Michigan, Nov. 13, 2010.

Number of Presentations: 2.00

Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

TOTAL:

Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

TOTAL:

Number of Peer-Reviewed Conference Proceeding publications (other than abstracts):

(d) Manuscripts

Received Paper

TOTAL:

Number of Manuscripts:

Books

Received Paper

TOTAL:

Patents Submitted

Patents Awarded

Awards

Graduate Students

NAME	PERCENT_SUPPORTED	Discipline
Emily Alden	1.00	
FTE Equivalent:	**1.00**	
Total Number:	**1**	

Names of Post Doctorates

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Names of Faculty Supported

NAME	PERCENT_SUPPORTED	National Academy Member
Aaron Leanhardt	0.17	
FTE Equivalent:	**0.17**	
Total Number:	**1**	

Names of Under Graduate students supported

NAME	PERCENT_SUPPORTED	Discipline
Charlie Steiner	1.00	Physics
Kaitlin Moore	1.00	Physics
FTE Equivalent:	**2.00**	
Total Number:	**2**	

Student Metrics

This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period: 1.00

The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:...... 2.00

The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:...... 2.00

Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):...... 2.00

Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering:...... 0.00

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Names of Personnel receiving masters degrees

NAME

Total Number:

Names of personnel receiving PHDs

NAME

Total Number:

Names of other research staff

NAME	PERCENT_SUPPORTED

FTE Equivalent:

Total Number:

Sub Contractors (DD882)

Inventions (DD882)

Scientific Progress

See Attachment

Technology Transfer

Two-Photon Optical Frequency Standard for Portable Optical Clocks Study

Precision frequency metrology has valuable applications in cutting edge physics and technology. Current standards require ultra cold atoms whose state preparation involves complicated engineering and sacrificing the number of atoms that can be used. The novel technique in our proposal allows us to access the narrow linewidth properties of a clock transition without elaborate state preparation or sacrificing the number atoms we address. In fact, we will be able to observe fractional frequency stability of 10^-15 after a few seconds in a room temperature vapor cell.

The basic experimental objectives at this stage are exciting and detecting the clock transition. We've designed and built a high-power, narrow-linewidth laser and we've designed a Hg vapor cell with buffer gas that will facilitate relaxation at detectable wavelengths. The laser system combines cutting edge technologies to produce a very powerful laser at 531nm at minimal cost. The most notable tool is the use of single pass periodically poled crystals for SHG. Only recently has the engineering of these crystals produced sufficiently high efficiency to make them viable [1], and the crystals also bring with them the virtue of minimal alignment and no need for locking electronics. Despite some delivery delays, we currently have a 4W laser at 531nm that is stably scanning over all our wavelengths of interest, see figure 1. The easiest detection mechanism is to utilize a buffer gas of NH3 which is known to produce a UV cascade photon that uniquely signals population in the 3P0 clock state [2]. We have these vapor cells in place and appropriate optical filters for clock state detection.

Another virtue of this experiment is that some of the specific transition frequencies are known to us making the search for first signal easier. The fermionic lines of Hg have been measured and localized to 0.5 MHz precision [3]. With the use of a reference I2 cell, and specifically a known I2 transition located 450 MHz from a known Hg transition, we are able to scan the window where Hg signal is anticipated. To execute this efficiently, we've implemented a double pass AOM so that we can simultaneously scan the I2 and the Hg regions. This will give us meaningful time savings and resolution improvement as we aggregate scan to looks for subtle signals at this early stage.

We will be able to produce unpublished I2 hyperfine structure of this transition shortly, and we will use this hyperfine structure as preliminary lock for the laser and scan reference in the Hg hunt. We'll be using 3rd harmonic demodulation to produce uniquely resolved hyperfine structure at this wavelength. In fact, our seed laser wavelength window is surprisingly large, and so will likely be able to do this 6-7 surrounding transitions, contributing further to useful transition atlas that I2 is becoming.

We have completed the essential preliminary steps for detecting this Hg transition using our novel two-photon excitation scheme. We have enacted stable control of our laser for precise scanning and detected the reference I2 transition that will enable us to precisely search for the neighboring Hg lines. We have the tools to detect new Bosonic lines of Hg and demonstrate the viability of this novel clock excitation scheme.

After we detect this transition the next step will be to reduce or remove all line broadening techniques we've used for initial detection. This will especially include exchanging the use of NH3 buffer gas for an optical detection channel. We will install a 405nm laser to excite atoms in the clock state to the nearby 3S1 level. This scheme will enable fast detection of the transition without the broadening we observe from a buffer gas.

At this time, we have installed a 405 nm diode laser system and are beginning to look for Hg atoms in the 3P0 state by driving the 3P0 --> 3S1 transition, which decays to the 1S0 ground state via the emission of two photons – one at 435 nm and one at 254 nm. We plan to detect the 254 nm photon.

[1]G. K. Samanta, S. Chaitanya Kumar, and M. Ebrahim-Zadeh, **Optics Letters**, Vol. 34, Issue 10, pp. 1561-1563 (2009)
[2]C. G. Freeman, M. J. McEwan, R. F. C. Claridge and L. F. Phillips
Trans. Faraday Soc., 1971, **67**, 2004-2008
[3]M. Petersen *et al.*, **Phys. Rev. Lett**. **101**, 183004 (2008).

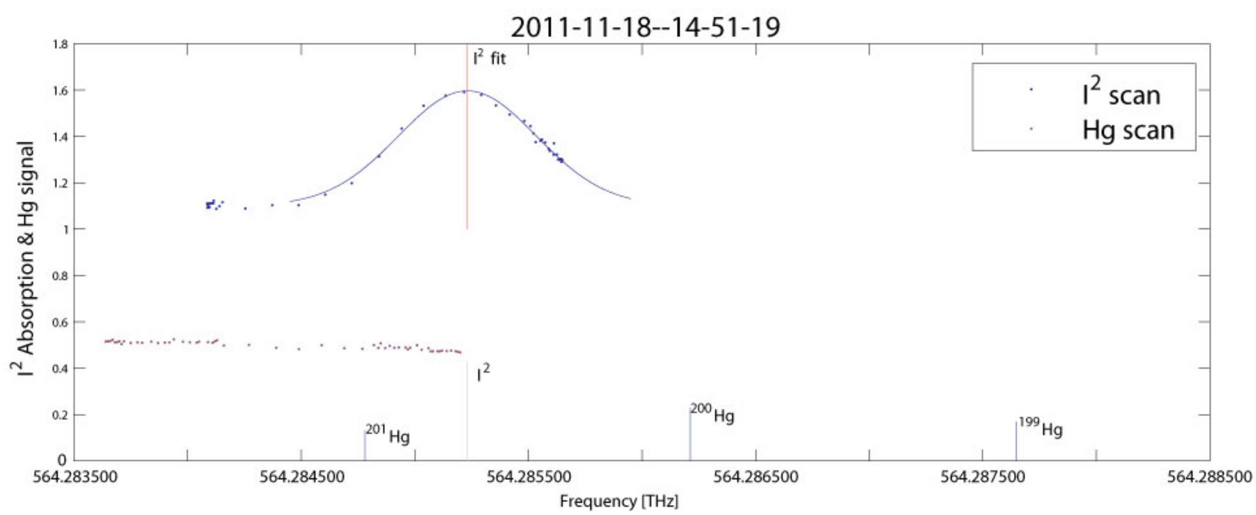

Figure 1: Spectroscopy of the reference R126(36-0) I2 line. This line will serve as a pivot to search for the neighboring Hg lines. The x-axis has the published and extrapolated I2 and Hg lines we are interested. We have performed stable scans over all these wavelengths.

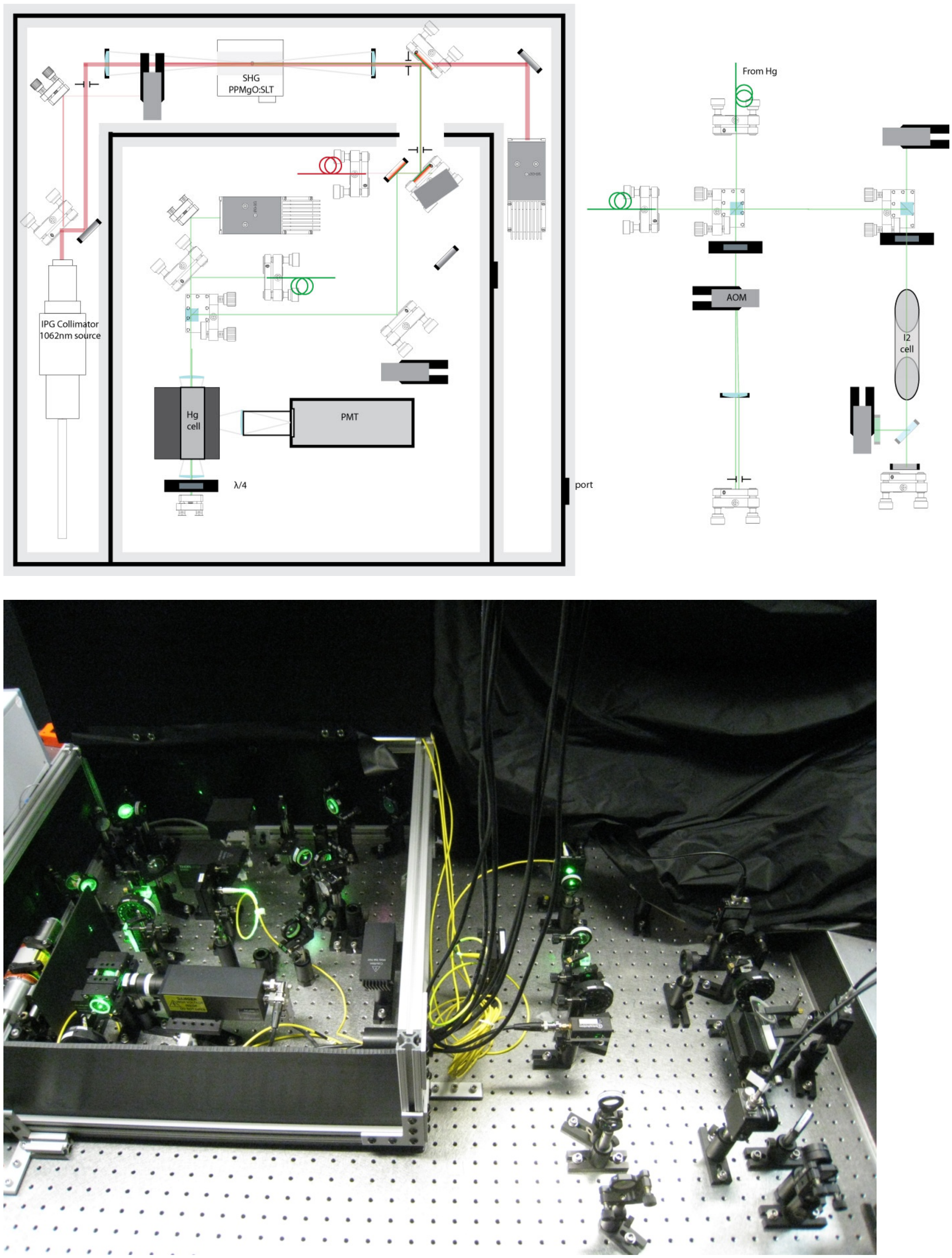

Figure 2: Hg and I2 experimental schematic and photos.